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The cultural barriers to a low-carbon future: A review of six mobility and energy transitions across 28 countries

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ABSTRACT

This review focuses on how culture can complicate and impede attempts at promoting more efficient, more sustainable, and often more affordable forms of mobility as well as energy use in homes and buildings. In simpler terms: it illustrates the cultural barriers to a low-carbon, low-energy future across 28 countries. Rather than focus on energy supply, it deals intently with energy end-use, demand, and consumption. In terms of low-carbon transport and mobility, it examines the cultural barriers to aggressive driving, speeding, and eco-driving; automated vehicles; and ridesharing and carpooling. In terms of cooking and building energy use, it examines the cultural barriers to solar home systems, improved cookstoves, and energy efficient heating, cooling, and hot water practices. For each case, the review synthesizes a wide range of studies showing that culture can operate as a salient but often unacknowledged barrier to low-carbon transitions as well as sustainability transitions more generally. The paper concludes with recommendations aimed at catalyzing the effectiveness and efficiency with which policymakers, researchers and practitioners are able to research, develop, demonstrate and deploy culturally appropriate technologies and policies for a low-carbon transition.

1. Introduction

Culture, defined as "the ideas, customs, and social behavior of a particular people or society," [1] is perhaps one of the most prosaic but still heavily utilized concepts in academia. The concept of culture has often taken specific forms, such as the "national culture" of a country or geographic space [2], the "market culture" of an economy [3], the "organizational culture" of a business firm [4], and the "medical culture" of the healthcare profession [5]. Political cultures range from full open democracy to closed authoritarian regime [6]. "Energy" or "sustainability culture" has been posited as the social norms, material artifacts and energy practices that reflect and shape consumer behaviors [7, 8]. Most relevant to this Review is the notion of "cultural logics", or the shared understanding of the motivations and intentions within a society, which "can greatly affect the production, distribution, and consumption of energy, often in unpredictable ways." [9] Culture, especially shared norms, values, and mutually reinforcing behaviors, is nonetheless often invisible, especially to those within a given society [10].

In this paper, we ask: how does culture act as a barrier to low-carbon energy transitions? How can insights gained about cultural barriers guide energy planners and policymakers? We take culture as a proxy for local societal practices, beliefs and behavioral routines, as well as their manifestations. Although various definitions exist for the notion of low-carbon energy transitions, we define them as a change in the sources and/or uses of energy that ultimately lower greenhouse gas (GHG) emissions [11]. The International Energy Agency, World Energy Council, World Economic Forum and a large number of major energy corporations are consistent in their views that our global energy and economic system is shifting from one that relies almost entirely on fossil fuel-based energy to one with a much greater reliance on low-carbon, sustainable energy generation and consumption [12–16]. In tandem, a global effort is being made to expand access to modern, more efficient and renewable energy services. Lack of access to electricity and dependence on traditional fuels for cooking and heating remains an enduring economic development issue for many countries, one that has catalyzed significant international momentum towards universal energy access via initiatives such as Sustainable Energy for All, "pro-poor" technology transfer, and Sustainable Development Goal 7 (SDG 7) [17–20].

This transition is underpinned by rapid advances not only in clean energy technologies, but also digital technologies that are reshaping the means by which energy generation and consumption take place [21–23]. Hence, throughout the remainder of this century planners and policymakers will be confronted with the challenge of safely deploying energy technologies that increasingly automate the means by which energy is supplied and consumed while effectively meeting massive

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energy demand growth in parts of the world where even the most basic energy services currently do not exist.

In this Review, we address these global sustainability concerns through a focus on how culture can act as an impediment and complicate attempts at promoting more efficient, more sustainable, and often more affordable *use* of mobility as well as energy *use* in homes and buildings. This synthesis of a wide range of studies shows that culture can operate as a salient but often unacknowledged barrier to low-carbon transitions as well as sustainability transitions more broadly. Unlike a vast body of studies that look at the cultural barriers to energy supply—including renewable energy [24,25], distributed generation [26–28], biofuel [29,30], and nuclear energy [31,32]—we instead examine the cultural barriers to energy consumption and end-use. This is because through their consumption behavior, households are responsible for 72% of global greenhouse gas emissions [33], making energy use on the demand-side a vital part of global energy and climate policy agendas [34–36].

The Review therefore explores culture and cultural barriers through the lens of six comparative and ongoing low-carbon, sustainability transitions. These six examples or case studies (Table 1) were selected to represent not only a diversity of sectors (power, buildings, transportation) but also a diversity of technologies (automobiles, solar home systems, cookstoves, built environment) and practices (driving, working, sharing, lighting, cooking, and heating). They also feature heavily in current debates and discussions about sustainability. Automated vehicles, and ridesharing and carpooling, are for example emphasized as critical "revolutions" that could transform how mobility is provided in the future [37–40]. Similarly, solar home systems [41,42] and improved or cleaner cookstoves [43,44] are advanced as instrumental in expanding access to modern energy services, which can literally save millions of lives a year, especially among women and children suffering from indoor air pollution in developing economies [45]. The energy efficiency of buildings, and in particular heating [46], is seen as a critical decarbonisation challenge that needs to be addressed to reach current targets for climate change mitigation. Collectively, our six cases also encompass the three intertwined prongs of sustainability – environment, society and economics [47]. The formal methodological literature refers to this analytical approach as a qualitative cross case comparison [48], the idea being such a comparison offers more generalizable findings than from a single case. Furthermore, for each case, we draw from evidence from across 28 countries, synthesizing from multiple disciplines and sources, similar to qualitative factor analysis or qualitative meta-analysis.

As Table 1 reveals, our cultural approach includes not only practices (the meanings, routines, skills, and knowledge utilized in "doing" things related to mobility or energy services), but also particular energy using systems and devices that are the material artifacts of cultural dynamics [49,50]. The approach differs from purely practice-based approaches that take the practice (e.g. bathing, cleaning, cooking) as the unit of analysis [51] and not a particular technology, country or region. This is an important distinction because many social practices have little to do with culture, and many cultural influences have nothing to do with practices [52,53]. Further, multiple practices can be involved in a given low-carbon transition, and our assessment goes beyond practices to include other key cultural elements like religion and beliefs, which do not necessarily fit squarely inside practice theory.

2. The cultural barriers to low-carbon transport and mobility

This section examines the negative influence of culture on three transport and mobility cases: aggressive driving, autonomous mobility (or self-driving cars), and ridesharing and carpooling (sometimes called shared mobility).

2.1. Aggressive driving and speeding

Aggressive driving—behaviors such as tailgating, speeding, horn honking, traffic weaving, profanity, obscene gestures, headlight flashing, red-light running, and blocking the passing lane [54]—have substantial implications on energy use and climate change. In Germany, the impact of different driving styles and route characteristics have major impacts on exhaust emissions [55,56]. Portable Emissions Measurement Systems have shown that aggressive driving leads to higher emissions as compared to normal driving, 20–40% for carbon dioxide and 50–255% for nitrogen oxide [57]. In Portugal, aggressive driving significantly impacts energy consumption and emissions, with energy consumption increasing by more than ~200% and emissions by 330% for aggressive driving compared to non-aggressive driving with collective social daily costs reaching as much as €52,500 [58].

How does culture shape aggressive driving practices? Cultural norms of macho-ness, masculinity and "speed" seem to lead to aggressive driving [59]. In the United Sates, due to norms of masculinity, men are more likely to be impatient and frustrated when driving; more likely to also rev engines (wasting energy); and more likely to honk at traffic at

Table 1
Summary of the cultural barriers facing six low-carbon transitions across 28 countries.

Case study	Sector(s)	Technologies Covered	Practice(s)	Cultural dynamics	Country Example(s)
Aggressive driving	Transport	Personal light duty vehicles (cars)	Driving, speeding	Masculinity, macho-ness, aggression, dominance	Australia, France, Germany, Portugal, Romania, Serbia, United Kingdom, United States
Automated mobility	Transport, information iechnology	Personal light duty vehicles (cars), heavy duty vehicles (trucks, freight)	Driving (in high levels of automation), biking, walking	Ethnic bias, discrimination	United Arab Emirates, Netherlands
Ridesharing	Transport, information technology	Personal light duty vehicles (cars)	Driving, commuting	Safety, social status, social exclusion, social awkwardness	Denmark, United Arab Emirates
Solar home systems	Buildings (households), energy (electricity)	Solar photovoltaic panels, batteries, inverters	Lighting, entertainment	Vandalism, health, vitality	Bangladesh, Mongolia, Nepal, Papua New Guinea, Thailand
Cookstoves	Buildings (households), energy (thermal energy)	Biomass cookstoves, natural gas cookstoves, solar cookstoves, LPG cookstoves	Cooking	Gender norms about motherhood and childminding, cultural significance of smoke, notions of impurity and sanctity of fuel sources	Bangladesh, Botswana, Burkina Faso, Ethiopia, India, Nigeria, Timor-Leste, Zimbabwe
Energy efficient heating	Buildings, energy (electricity, natural gas)	Heating ventilation and air conditioning systems (HVAC), low-energy buildings, zero-energy homes, office buildings	Heating, cooling, hot water, bathing	Thermal comfort, control	China, Japan, Norway

Source: Authors

stoplights (leading possibly to road rage and consequent traffic accidents) [60]. Similarly, in Serbia and Romania, men report higher levels of aggressive driving than females [61]. In France, masculine norms lead to a culture of "speed" where 56% of young drivers, many of them male, admit to speeding habitually [62]. Psychological studies of French speeders suggest they do so due to social pressure from their peers as well as enhanced feelings of controlling time while speeding [63]. In Australia, speeding occurs across both genders, with female "high intenders" speeding because of familiarity with roads but men more likely to speed because of having greater perceptions of support from friends [64].

Other work has emphasized how being "macho", that is, being perceived as strong, dominant, and in control, or someone who strongly experience emotions such as anger [65–67], leads people to speed. This could explain why in Germany, young men are overrepresented by a wide margin in road traffic accidents, accounting for 30% of all accidents but representing only 8% of the adult population [68]. Interviews with such drivers suggest that "macho identity" creates inclinations of young men towards risk taking (and in some cases violence). European cultural norms about being assertive and dominant as a way of signifying strength and status among peers is another cause of such behavior [69]. A study in the United Kingdom even showed that such cultural norms can influence those driving hybrid electric vehicles. Specifically, some drivers have attempted to recharge their vehicles not by plugging in at home or at work, but by aggressively running the internal combustion engine and then using the re-generative braking system, thereby negating the carbon savings [70].

2.2. Automated mobility

The future of personal mobility is often linked with the broad deployment of shared, electric (EV) and autonomous vehicles (AVs) [71, 72]. However, in this subsection we focus on the AV aspect and show how culture becomes not only embedded via vehicles, driving practices or end-user behavior, but also via the programmers and modelers doing the automation. While cultural factors that influence the perception of AVs and willingness to utilize them has been covered elsewhere [37,73], this section concentrates on automated mobility *per se* and more specifically the artificial intelligence (AI) systems that provide their perceived intelligence and cultural awareness, or lack thereof. A growing number of challenges have been observed with AI systems used in the organization of society and its basic institutions [74] and hence assessment of the challenges that arise when incorporating AI systems into the complex sociotechnical domain of automobility is warranted.

While the sustainability benefits of car sharing and EVs powered by renewable electricity are clear, the implications of vehicle autonomy, or the ability of a vehicle to drive itself, are less obvious [75,76], but entail potentially positive impacts [77]. For context, Wadud et al. have shown that high levels of automation for vehicles can decrease or increase total road transport energy, with the ultimate outcome depending on the extent to which autonomous transportation reduces the energy intensity and energy demand of travel, versus increasing overall demand for travel due to convenience and participation of user groups such as the elderly and disabled [78]. In the four scenarios they discuss, total road transport energy, including both light and heavy duty vehicles may either decrease by up to 40% or increase by more than 100%. In their best-case scenario for energy reduction, it is not AVs *per se* that provide the benefit, but rather the ability for AVs to impart such benefits as smoothed traffic flows, reduced traffic accidents and embodied eco-driving practices. Arbib and Seba have perhaps optimistically suggested that the synergies among AVs, EVs and ride sharing will lead to a rapid transport-as-a-service (TaaS) revolution that results in a reduction of over 90% in CO^2 emissions from light-duty vehicle road transportation in 2030, compared to business-as-usual projections [71,79]. While it is clear that the potential benefit of AVs to low-carbon energy transition is somewhat ambiguous, it is promising that nearly all of the leading global automobile manufacturers are actively pursuing the commercial introduction of vehicles that are not just autonomous, but also electric and shared [80].

In the case of an AV, culture is essentially embedded in computerized systems and these systems then determine how the vehicle interacts with passengers, pedestrians and other motorists [81]. An AV is trained to recognize the environment around it using a variety of sensing mechanisms and then take "appropriate" actions as needed. As with all AI systems, however, AVs can have untended biases that are extremely difficult to fix [76,82]. Various studies, for instance, have indicated that AVs trained using AI machine learning techniques are likely to have pedestrian detection biases based on skin tone and culturally determined patterns of dress [83]. Such biases may make AVs more likely to hit and even kill non-white pedestrians, suggesting built-in racial biases [84].

In Arab countries, such as the United Arab Emirates, this means that not only would darker skinned Arab pedestrians be less likely to be recognized by AVs, their cultural attire, such as the Kandura (male body garment), Ghutrah (male head cover), Abaya (female body garment) and Gishwa (female face cover), are also likely to pose human-recognition challenges for AVs. Such observed and reported AV biases have led to public concerns in the UAE about driverless cars being racist and hence a public concern (see Fig. 1) [85].

Culture is also very important in determining how well an AV trained on specific sets of pedestrian data is able to anticipate pedestrian actions given the nuances of how body language translates to intended action in different cultures [86,87]. Further, even if an AV can perfectly identify pedestrians and anticipate their coming actions, the "appropriate" action for the AV to take may differ across cultures. For instance, the "morale machine" experiment has shown distinct cultural preferences for the categories of citizens whose lives should be spared in the case of an unavoidable AV collision with pedestrians [88].

Such issues are in contrast to the UAE government's favorable view of AVs [89] and the country's high ranking in KPMG's AV Readiness Index [90]. The UAE is not alone, however, in having clear cultural challenges to AV adoption that contradict government support for AVs and a perceived readiness for AV adoption. The Netherlands ranks at the top of the KPMG AV Readiness list and has one of the most favorable overall public perceptions of AVs in Europe [91]. Nonetheless, bicycling is extremely popular in the Netherlands and yet bicycles are cited as perhaps the most difficult detection problem that autonomous vehicle systems face [92]. In response to this challenge, an Executive for Automotive at KPMG in the Netherlands, stated that "in urban, crowded areas it will be very difficult to start autonomous driving." [93].


UAE

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Daniel Sanderson
March 11, 2019

SHARE

Driverless cars risk being racist, new research suggests

► Study claims some detection systems are less likely to see pedestrians with dark skin

A driverless car seen during testing in Singapore. AFP

Fig. 1. Public media claims about racism and automated mobility, 2019. Source: Authors

2.3. Ridesharing and carpooling

Shared mobility refers broadly to the sharing of vehicles (e.g., car sharing or bike sharing), and the sharing of rides (e.g., ride hailing). Car sharing (or a "car club" in the UK and Europe) involves the user paying an hourly (and/or mileage-based) rate to pick up a vehicle, use it, and return it somewhere [37]. The second broad category of shared mobility is ride hailing, typically defined as an app-based platform that allows users to request for a ride from a (at least semi-) professional driver—-with Uber and Lyft being the most well-known service providers and the dominant providers in the United States [37]. The net societal impacts of car sharing and ride hailing programs are uncertain, though both are often considered as a pathway to reduce vehicle ownership [94,95]. Other studies confirm that car sharing and ride hailing can decrease overall transit and taxi usage [96,97]. Both can also, when integrated with active travel and mass transit, support walking and healthier lifestyles [37]. Due to these arguments, Sperling [98] writes that mass adoption of carpooling is essential so that overall vehicle travel is reduced and sustainable transportation goals met.

However, in Denmark, cultural norms against ride sharing in the form of carpooling revolve around notions of safety, social awkwardness, and social exclusion. As one study with potential adopters of carpooling indicated, "Didn't your mother ever tell you not to get in a car with a stranger?" [99] Others have talked about notions of private space, suggesting that because "a car is a private thing, it would be strange to invite someone into this personal space." [100] Another stated that "the insecurity factor is a big one to overcome, it would be an awkward trip if I don't know the riders or if they behave unpleasantly." [101] A final batch of concerns mixed ridesharing with social exclusion, and maintained that one must have a private car to "fit in" or "be happy" in Denmark. As one respondent said, "Even though ridesharing offers many advantages, it does still not offer me the freedom and emotional status which I get by owning and driving a car." [102] Another explained that "it's a status issue, at least in rural Denmark people are shocked when they learn I don't have a car, many of my neighbors have two or more, it makes me feel like a white crow." [103].

In the countries of the Gulf Cooperation Council (GCC), the norm is private car ownership with 97% of residents traveling predominantly by private car, which is by far the highest percentage in the Arab world [104]. Furthermore, nearly one-third of GCC residents are unwilling to share a car with others [105]. Within the United Arab Emirates (UAE), one of the GCC member countries, more than 90% of residents have stated a preference to use a private car for nearly all activities and only 17% would be likely to participate in ride sharing with other passengers [106]. A key aspect of the car ownership culture in the UAE and across the GCC is the expression of class and wealth, which is a known automobility frame that is counter to ride sharing [75]. Particularly among Emirati (UAE) males, cars are a sign of status. Interviewed Emirati males have stated that their cars are where they spend much of their time, almost like a second home, and that they have a passion for driving [107]. Such sentiments are reinforced in the UAE culture by the highly visible presence of Formula 1 racing in Abu Dhabi and the establishment of the world's first Ferrari branded theme park also in Abu Dhabi.

3. The cultural barriers to cooking and building energy use

This section explores the role of culture in energy and building use, including solar home systems, cooking and improved cookstoves, and energy efficiency improvements in buildings such as heating. Some cases are discussed that show well-designed programs with sufficient financial incentives that promote low-carbon technology can still fail to achieve household adoption due to cultural reasons and/or lack of energy literacy. Moreover, as technologies get rolled out to more and more remote areas, they invariably come into contact with more isolated local cultures. The presented cooking and cookstove cases also provide a broader view of the interrelation between culture and sustainability transitions as health and social welfare are shown to be impacted more so than transition to low-carbon energy.

3.1. Solar home systems

Solar home systems consist of a solar panel, battery, inverter, charge controller, and usually two to three lamps and an extension cord that can power a small radio or television. They offer a meaningful way to displace fossil fuels or more polluting kerosene lamps for lighting. Yet, because they must be domesticated and adopted by households, they often run into cultural difficulties.

For example, in Bangladesh, solar home systems have been largely diffused as part of an international program aiming to empower women and generate skills and capacity among retailers. However, adopting households often have odd notions about what such solar devices "need" in order to function. For example, one family thought they needed to dismount their solar home system and take it "for a walk" every day so it "wouldn't get tired." [108].

In Papua New Guinea, solar home systems have been prone to unusually high rates of vandalism, sabotage, and theft. Under a *wantok* system rooted in tribal traditions, clans there share resources. Solar panels, which benefit a particular house or individual instead of the community, assault this system of *wantok*. Tribal communities have therefore smashed hundreds of solar panels or, worse, threatened their owners. One village elder stated that he would "never" want to purchase a solar panel because if "if I did put one in my village, but not all of the surrounding villages, they would kill me." [109].

In Nepal, solar systems have been installed more at a community level as a way to create min-grids or power remote telecommunications facilities. There, one Buddhist mother thought she needed to cover her solar home system with leaves to make it "part of nature," another thought a community-scale solar array would "dry laundry" and placed socks and underwear on it, as Fig. 2 reveals [110]. While drying laundry on a solar panel admittedly makes sense scientifically—the panel absorbs energy from the sun and a portion is converted to heat—it was certainly not the intended use for the community solar project, and likely interfered with other community services by reducing the electricity produced from the solar system.

In Thailand, a national program for solar home systems as a tool of rural electrification faced cultural struggles over the lack of maintenance, as well as tensions with local villages [111]. For example, the absence of a culture of repair among accepting communities meant that more than half (60%) of the systems were non-functional within a few years of the program's end. Moreover, the installation and use of the solar home systems created cultural tension within villages, especially among ethnic minorities, given that promotional materials were in Thai, but many local groups spoke other languages. Solar adoption also led to many households watching television, leading to some communities

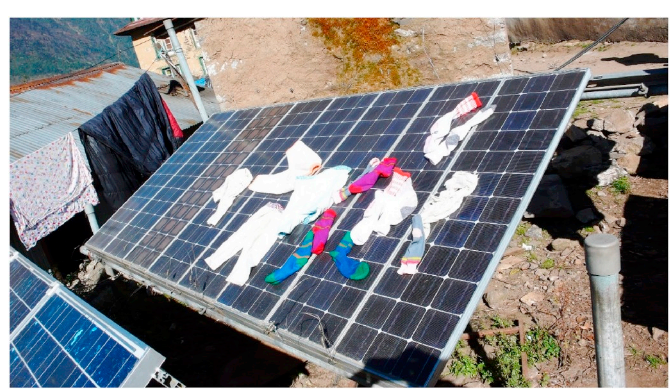

Fig. 2. The cultural (mis)use of solar photovoltaic panels in Nepal.
Source: Authors

believing that local ethnic identity was being further eroded and lost.

Lastly, in Mongolia, solar systems have been targeted at nomadic farmers and herders who spend as many as six to nine months roaming the countryside outside of the scope of the national grid. Solar home systems have become a portable and modular form of electricity supply critical for lighting and communication (via radios and phones). However, one family thought their solar system would work indoors and had positioned it inside their *ger* as a coffee table [112].

3.2. Improved cookstoves

Improved cookstoves, or cleaner cooking devices, use the term "improved" or "clean" because more traditional and conventional stoves have heating efficiencies averaging 10 to 12%, meaning as much as 90% of the energy content of the wood or charcoal used in them is wasted. Improved stoves require a switch away from charcoal or polluted wood to healthier fuels such soft biomass, crop residues, and firewood; they have a grate and an improved combustion chamber; and they almost always have a chimney [113]. They utilize higher temperature ceramics, fire resistant material, longer lasting metals, and possess more insulation and a better frame that guides hot gases closer to cooking pots. In some rural homes, especially in China, improved stoves are connected to radiators or space heaters so that heat can be recycled and/or vented to other rooms and some stoves send heat through pipes directly into a brick platform called a *kang* that occupants sleep on at night [114]. Biogas cookstoves capture methane from decomposing waste through anaerobic digestion and convert it into fuel. Solar cookstoves often use a simple set of mirrors to focus sunlight to generate heat. Improved biomass, biogas, and solar cookstoves can thus offer significant energy and fuel savings, and lead to consequent emissions savings from reduced fossil fuel use and/or deforestation [115].

Access to and use of improved cookstoves, however, is first and foremost mediated by cultural gender norms [116]. In most cultures around the world, women serve as the primary collectors of fuelwood for cooking, the primary cooks, the primary energy users, and the primary childminders, placing them at a higher risk to biomass smoke and negative health consequences [117]. For instance, women comprise the majority of those vulnerable to energy scarcity; time spent in fuel collection can range from one to 5 h per day, frequently with an infant strapped to a woman's back. As the Asian Development Bank has reported, "the energy-poverty nexus has a distinct gender bias: of the world's poor, 70% are women" [118]. As Fig. 3 illustrates, over the course of a typical year in Tanzania, a woman will spend almost 2000 h dealing with chores, fuel collection, cooking, and other tasks compared to only 500 h for men; that same woman will carry almost 90 tons whereas the same man will carry less than 12 tons [119].

Fig. 4 shows how the health impacts of traditional fuel use have a significant gender bias [121], and just how hazardous it is to young women and children [122]. Conversely, the benefits of energy access, when they do occur, are often not distributed equally or fairly, either, and are mediated by gender roles and cultural norms [123,124].

In addition to gender, very specific cultural practices of cooking mediate the success of cookstove adoption. In simpler terms, an improved or modern cookstove must be compatible with the cooking culture of a given community [126]. Speed of cooking, type or availability of ingredients, type and volume of fuelwood, taste and dietary preferences will all shape household adoption and use patterns. Cookstoves that cannot boil water quickly, or bake certain types of bread, for instance, are often rejected in favor of traditional hearths, ovens, and fires. Multiple reviews of cookstove programs around the world have concluded that such efforts can fail because they do not sufficiently consider local culture, or take into consideration traditional food preparation or fuelwood collection practices that are important to local identity and socialization [127–129].

We see this nexus of cooking and culture (and often gender) playout in many regions of the world. For instance, in India, field research has revealed that households will often reject new cookstoves because they cannot cook *chapatti* (a type of unleavened flatbread) [130] and cannot replace the history and familiarity embedded in traditional *chulha* stoves [131]. *Chulha* stoves, because they are relatively inefficient, bring women together during the arduous and time-consuming process of collecting wood. Further, their smoke is seen as critical to flavoring dishes and their waste heat is seen as warming the center of the home [132].

In Bangladesh, religious beliefs can impede the use of cleaner stoves. An aversion to pigs has prevented predominately Muslim households from adopting biogas units that would run on pig waste, despite the fact that such waste is much more efficient than dung [133]. Other households refuse to purchase cookstoves at all because they are uncomfortable with the idea of piping in gas from livestock and human excrement,

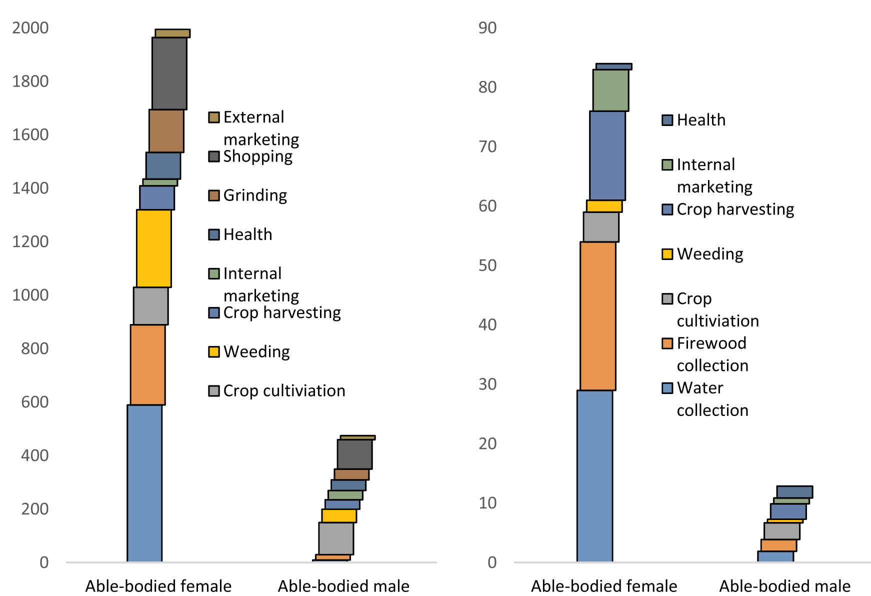

Fig. 3. Annual Differences between Women and Men in Tanzania for Chores (in hours) and Hauling Items (in tons).
Source: [120].

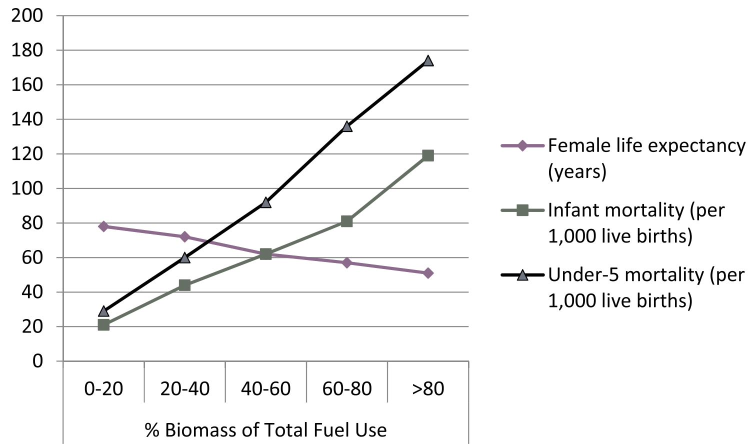

Fig. 4. Gendered health implications of traditional fuel use.
Source: [125].

which they see as impure. Another family thought they had to "add soap" to their waste to "make it clean" before it would work in a biogas digester.

In Timor-Leste (East Timor), many women refuse to use improved cookstoves because of cultural barriers relating to status as well as how food is believed to taste inferior to that cooked by more conventional and traditional stoves. Moreover, cultural issues have interfered with the ability of women to self-train, be patient, and learn the skills and tacit knowledge needed to use new stoves [134].

In Ethiopia, cultural misperceptions arose over concerns of a more efficient fire. There, cleaner burning ethanol stoves were rejected by some households due to an (improperly placed) fear that they would explode, or cause severe burns [135]. This led to considerable anxiety resulting in many potential adopters refusing to let such stoves inside their house.

In Botswana, a cultural stigma arose for the opposite reason, due to the lack of a fire. Because solar cookers prepare food without a visible flame, people have a natural skepticism toward adopting them. In the Tswana culture of Botswana, an open fire plays a significant social role as a space where families gather around the *leiso* to discuss the day's events. It is also the place where visitors are supposed to be welcomed for a warm cup of tea. Substituting a normal fire with a solar cooker interferes with these cultural meanings [136].

Similarly, in Burkina Faso, many small restaurants prepare their products (such as bread) in the middle of the night so they can serve shift workers who begin their day before the sun rises. This clearly means solar cookers, which cannot operate at night, cannot meet the needs of such vendors. Solar cookers also cannot generate the required number of bread loaves to meet demand, which is why most shops continue to rely on traditional baking methods [137].

In other cultures, smoke from cookstoves is now part of religious practices in some communities, where women pray to "hearth gods" composed of smoke. As Coyfe writes, "People were reluctant to use solar cookers because they believed the god of the household hearth was an important spirit who would be offended if meals were not cooked on a fire on the hearth." [138] In this way, the service they desire, spiritualism, is one eroded by modern smokeless cooking devices. Smoke is also a way of keeping insects out of homes, and it can engender a smoky space where women can gather to discuss their personal issues without the presence of men, who avoid the space [139]. In Zimbabwe, sunlight and natural light are seen as having a spiritual significance relating to spirits and signs from Heaven. Capturing this light is believed to be "stealing from above". As one woman remarked, solar cooking was "unnatural", and went against God [140].

Similarly, in Nigeria, smoke has a cultural significance in terms of both preserving food and contributing to the health of a building. Wood smoke is particularly valued as a means of curing pre-salted fish or meat, a crucial form of food preservation given the lack of electricity for refrigeration. It was also believed to strengthen buildings and solidify walls, especially mud bricks. Akintan et al. conclude that in such cultures, the value of cooking smoke for food and building preservation are believed to outweigh "relatedly minor nuisances" such as stinging eyes and headaches [141].

3.3. Energy efficient heating and hot water use in buildings

Our final example is energy efficient heating and energy use in buildings. The International Energy Agency notes that heat is the largest global end-use for energy, and that providing heat for homes and industrial applications accounts for roughly 50% of total energy consumption [142]. Yet the consumption of heat and different heating profiles have striking social and cultural aspects [143–145].

In Norway, for example, families tend to heat all rooms, even those not in use, so the entire house is made into a heated envelope that allows occupants to move freely between the rooms [146]. This also contributes to important symbolic value of heating the home to achieve a perpetual level of comfort. The Norwegians call this *koslighet*, a state of coziness virtually mandatory in Norwegian living rooms. Norwegians generally shower *or* bath, not both, but do not reuse water, leading to increased demands for reheating fresh water. Hot water is also often used to wash clothes and dishes.

In Japan, the traditional household heater is the *kotatsu*, a small unit usually placed under a table or bed, with supplemental comforters or blankets placed to trap heat for those huddled around the table [147]. However, in Japan, additional heating needs are met by inefficient electric carpets or small kerosene heaters. The Japanese also take multiple baths and showers each day, and some are even known to take long showers where they clean clothes and dishes inside the bath—leading to greater demand for hot water. Bathing is thus a daily obligation and a hobby, and it can entail hot water use not only within homes and offices, but also within the more than 20,000 public baths across the country designed for this purpose [148]. The toilet itself is also a semi-sacred site for the use of hot water and cleansing. In Japan, households often feature toilets that can warm and wash one's bottom with cold, moderate, or even hot water, "whisk away odors" with built-in fans, produce water noises to drown out sounds, and play relaxation music. The problem is that such toilets—one of them is shown in Fig. 5— use more energy than dishwashers or clothes dryers use, and account for about 4% of household energy consumption nationwide [149].

In other cultures, such as China, a practice of opening windows often

Fig. 5. The Toto TCR530C luxury toilet in tokyo, Japan.
Source: Authors

erodes energy efficiency and heat gains. There, for example, the practice of *tong feng*, "airing the room" to keep fresh air available has the unintended consequence of venting precious heat out of buildings during the winter [150]. This can occur in both residential/domestic as well as business/office settings. In Shenyang, China, for example, interviews with households revealed that many felt the need to open windows to improve air quality, with the behavior common across many different building types and "dramatic" heat losses as a result, especially during colder outdoor temperatures [151]. Another longitudinal study of occupant behavior in office buildings in China revealed a multitude of instances of "improper window use" practices [152]. During the winter, occupants would frequently leave the window open during the day, but many times also overnight, leading to more severe heat losses.

4. Discussion: implications for low-carbon mobility and energy transitions

In sum, our six innovations or transitions of eco-driving, automated mobility, ridesharing/carpooling, solar home systems, improved cookstoves, and energy efficient heating and hot water reveal that culture remains an important factor throughout. Here, in this section, we synthesize from across the six cases to reveal how culture intersects with mobility, housing, or consumption, with possible insights for those concerned with energy services [153,154] as well as sustainability transitions more broadly [155]. We center this discussion on three core themes: cultural salience, cultural complexity, and further research.

4.1. The salience of culture

Firstly, our analysis reveals that a cultural orientation towards energy analysis emphasizes elements as diverse as productive energy, mobility, and even spirituality and gender practices. It helps elucidate the fact that cultural attitudes and social expectations play as significant a role as price signals, national programs, and regulations in impeding the use of energy applications that are central to a low-carbon energy transition. No matter how well developed or perfected a given energy technology or energy system becomes in a laboratory, it could have little to no impact without systematic and scientific efforts to ensure such technologies are culturally compatible.

Culture can be a salient barrier to the emergence of climate friendly technologies and behavioral practices [35]. Analogous to a chemical reaction, a low-carbon and/or sustainability transition entails society moving from one state to another with, in most cases, an "activation energy" or barrier to overcome (see Fig. 6). A catalyst provides an alternative reaction pathway that lowers the activation energy required to pass through the transition state in a chemical reaction, resulting in a faster reaction. In keeping with this analogy, the activation energy for positive societal change resulting from new or significantly modified low-carbon energy technologies and behavioral practices is the combined effort required to overcome social, technical, economic and political hindrances from ingrained regimes from that must change in order for beneficial sociotechnical change to occur. A catalyst for change that can lower the social contribution to activation energy is cultural awareness and guidance, as we discuss in more detail in the conclusion.

In our cases, automated mobility is a radical transition both technically and behaviorally and hence the activation energy for realizing potentially positive societal impacts are expected to be significant. Ridesharing requires significant behavioral transition but may have a relatively lower activation energy given that the underlying technological change is incremental in nature. The remainder of our cases would have modest activation energies given that neither the technologies nor the behavioral transitions are radical, although cookstoves, a less radical technology, may still require or in result radical changes in cooking culture. This is not to say, however, that such transitions do not need to be catalyzed. As in the physical world, some reactions proceed too slowly to be of practical consequence without catalysis.

4.2. The complexity of culture

Second, while some analyses of low-carbon transitions might often neglect explicit consideration of culture, the fluidity of culture as a concept enables culture to encompass nearly all key dimensions of low-carbon transition. Some emerging energy and low-carbon innovations can create, challenge, or reinforce existing cultures; in other situations embedded cultures can challenge, shape, and entrench particular low-carbon innovations and practices. Ideas, customs, and social behavior merge with technological artifacts and material infrastructures to create cultures (or sub-cultures) of driving, automation, riding, domesticating, cooking, and heating. Furthermore, such cultural influences remain dynamic—never static—and culture itself represents a contested,

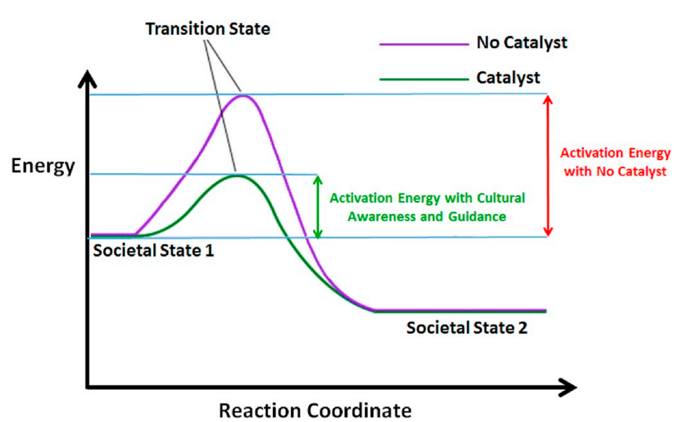

Fig. 6. Energy transitions, culture, and society.
Source: Authors

evolving, and at times profound source of social and economic aspiration as well as action [156].

As summarized in the following list, in this study we have demonstrated that culture encompasses a broad range of norms, practices and material artifacts within different societies and technology platforms:

- Social customs such as serving tea, hosting visitors, and signifying a comfortable, clean or hygienic home;
- Social signaling and materialism, such as conspicuous consumption or the projection of wealth or power;
- Social norms, including peer pressure, notions of risk and adventure among young adults, and priorities such as control and speed;
- Spiritual beliefs including smoke gods and particular views about the proper use (or misuse) of fire, smoke, light and solar energy;
- Practices, such as preserving food or the use of smoke for strengthening buildings, or bathing;
- Gender roles and patriarchy, including men speeding and dominating, and women cooking, collecting wood, and raising children;
- Misperceptions, biases and perceived discrimination arising from the embodiment of culture in AI programming, software and machines;
- Misperceptions, biases and perceived discrimination arising from software and machines interacting in societies where they lack sufficient training related to cultural norms and practices.

From this list, the latter two points are of particular importance to the intersection of culture and energy as they directly relate to the rise of AI in energy or mobility systems, which is a relatively new but important paradigm [157], that reinforces the call for scientific inquiry of machine and human–machine ecologies [158].

For instance, as automation and intelligent systems become increasingly ingrained in the energy system, software and machines will need to be sufficiently culturally aware and/or embody culture to the extent that insurmountable barriers to energy transition do not arise. Considering transportation, even if AVs are configured to optimize energy consumption and mitigate the types of aggressive driving behavior discussed in this paper, they will still require tailoring to local contexts for safe and efficient operation that will allow them to earn the trust of users, which presently is limited [159,160]. AV manufacturers may therefore be faced with localization requirements that far exceed anything encountered to date.

Ride sharing services also have great potential to promote better driving behavior while reducing transportation demand and ultimately saving considerable amounts of energy and carbon emissions. However, cultural nuances in personal transportation will make ride sharing a business that is service first and technology second with significant tailoring to local context required. It is therefore no surprise to see the proliferation of successful local ride sharing companies such as Didi Chung in China, Go-Jek in Indonesia, Grab in Singapore and Ola in India despite the fact that a company like Uber has exportable software and has been eager to expand internationally [161].

The cases discussed concerning distributed energy are central to the notion of low-carbon energy transition since the future of energy demand growth is in developing countries where distributed energy is expected to play a major role. While it is true that utility-scale renewable energy systems incur costs for transmission and distribution and may limit private sector involvement [162], distributed renewable energy may prove more challenging than expected to reach the considerable scale required for a global energy transition. Energy efficiency as an "obvious" means of achieving sustainability and reduced energy consumption [163] is in fact not so obvious upon further consideration of cultural barriers that arise when dealing with cultural norms and practices that may inhibit their adoption . We also highlight cases concerning cooking and cookstoves to reinforce the notion that while culture is a central element to low-carbon energy transition, it also plays a major role in the broader elements of sustainability that include health and social welfare.

4.3. Future research on culture

Admittedly, in this paper, we only focus (due to lack of space) on culture as an impediment. To be sure, other work could investigate more deeply the implications of different cultures in terms of their energy and greenhouse gas emission outcomes, their levels of energy use, relative efficiency, and future energy habits [164,165]. Moreover, culture and local knowledge need not always serve as a barrier; they can support and even accelerate low carbon transitions.

In the domain of transport and mobility, Careem became an attractive alternative to Uber in the Middle East because it embraced local cultural and catered to it [166]. Careem's success has indeed been enabled through cultural awareness [167]. Careem recognized very early the predominance of personal car usage in the GCC and hence the opportunity to engage a very large female population in Saudi Arabia that had not been allowed to drive until only recently [168]. Saudi women, who indeed have been about 70% of Careem's user base in Saudi Arabia, culturally require that their reputations not be in jeopardy when riding in a stranger's car. For this reason, Careem drivers in Saudi Arabia are trained to follow all social norms, such as not engaging with local women in conversations while driving and not glancing at them in the rearview mirror. Careem also has allowed female riders to be far more selective in choosing drivers than is the norm for ride hailing in other regions and countries. Careem has further been able to alter the perceptions of drivers for hire in the GCC, who are mainly expatriates from countries such as Pakistan and India and at the very low end of the regional social class system. Careem calls its drivers "Captains" to impart a greater level of respect on the job. Through such efforts, Careem has even been able to tap into the cultural pride of Arabs to engage them as drivers [169].

In the domain of cooking and buildings, cultural dimensions have also been successfully incorporated into programs or design efforts. For example, one solar cooker project in Central America failed to achieve widespread adoption because women had to sit, stoop, or crouch to use the cookers. In response, project managers started modifying the units with legs so that ovens were closer to the waist of cooks, improving acceptance greatly [170]. In Bangladesh, a taboo against letting men inside homes during the day enabled Grameen Shakti to empower women as entrepreneurs and technicians helping install and repair solar energy systems, and in Sri Lanka, a culture of *shramadana* convinced communities to give their own time or materials for the civil works and construction of micro-hydro units [171].

These examples, and others, imply that culture need not always impede the adoption of low carbon technologies and practices, which is an important consideration for future research.

5. Conclusion and policy implications

The predominant approach to considering clean energy transitions based simply on techno-economic considerations may provide misleading conclusions when cultural adoption is not carefully considered. Culture demands new forms of research and the input of local communities into the research and planning process as well. But how can culture be properly factored in policies and interventions to support low-carbon energy transition? We offer three sets of suggestions for three different stakeholder groups: policymakers and planners, researchers, and practitioners of energy development programs.

In the government, policymaking, and planning domains, ministries and statistical agencies responsible for energy, climate, and buildings should begin to collect data on culture and cultural trends. Governments could stipulate greater community involvement during licensing and permitting discussions so that cultural bias is minimized. Governments could also suggest that cultural modification be considered as a core competence needed within the entities tasked with planning and implementing low-carbon transitions. Lastly, policymakers of all types ought to move from a focus always on individuals to a recognition that group-based and collective phenomena—such as culture—shape and influence aspirations, capabilities, and agency for low-carbon transitions [172]. However, such culturally aware foci, and any policies that result, must also be inclusive and resist overly unjust, hegemonic, or narrow narratives of development and implementation [173].

In the research domain, energy system modelers can be sensitized to cultural diversity and trained to recognize and minimize racial, gender, cultural, and other forms of bias. This would complement ongoing calls for "data literacy" [174] or "algorithmic justice" [175] and "data justice" [176] within the modeling, data analytics, and machine learning communities. The funders of research or the principle investigators designing projects should be encouraged to include cultural components and research questions in qualitative projects that collect data via interviews, focus groups, and other public fora, helping to make cultural dynamics visible. Lastly, funders and investigators should explicitly consider cultural diversity, alongside interdisciplinary diversity and perhaps demographic diversity, in the assembling of research teams. This need is recognized in the artificial intelligence community [177] and should diffuse more into the energy community, particularly as artificial intelligence continues to gain importance in energy system design and operation.

In the energy practitioner domain, program managers should consult with community members and leaders about their energy or mobility needs before implementation begins rather than after programs are already being implemented. Moreover, program officers and managers can draw from the insights of previous moral licensing attempts in behavioral energy conservation policies, projects, and greening campaigns, perhaps cataloging an inventory of options and suggestions. Instead of directing efforts almost exclusively at lowering costs and improving technology, planners might want to also consider strengthening the institutional capacity of local community-based organizations and informing and educating end users about the technologies that they will encounter. This would involve moving beyond mere after sales service to hands-on training and maintenance sessions. Instead of frequently relying on imported western technology, programs could incentivize locally designed, manufactured, and distributed technologies that are developed by local contractors who intimately understand the cultural dynamics of the customers they are supposed to serve.

Ultimately, the true potential for low-carbon transitions will remain stunted without sensitive and appropriately designed research, policy, and programs that actively overcome the barriers created by culture, in all of its salient and complex manifestations.

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